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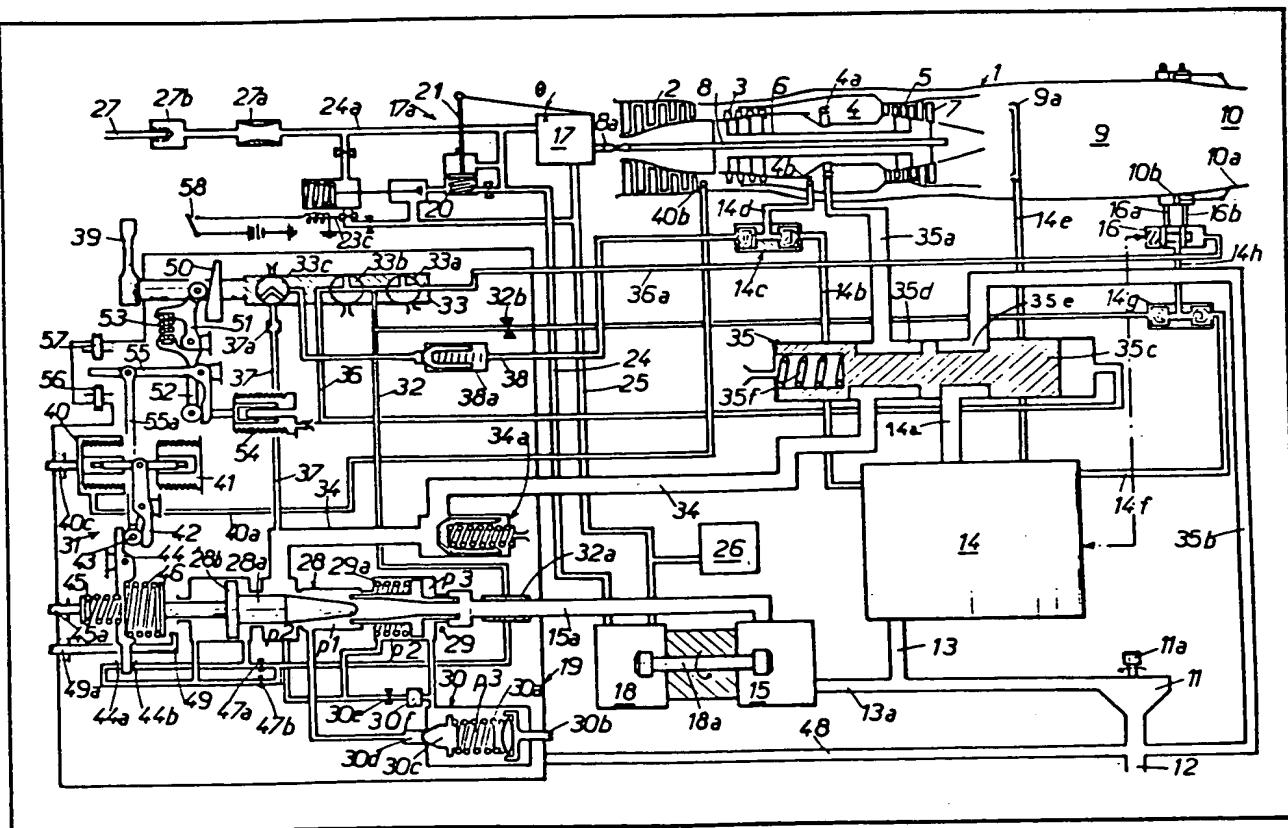
**Boulevard Victor, 75015
Paris, France**
(72) Inventor
**Jean Paul Francois Gilbert
Briote**
(74) Agent
Mathisen, Macara & Co.

(54) Gas Turbine Engine Fuel System

(57) The fuel system includes a positive displacement hydraulic pump

(17) driven by the engine and associated with a pressure regulator (17a), the pump delivering hydraulic fluid at constant pressure through a pipe (24) to drive a positive displacement hydraulic motor (18) which is coupled to drive a positive displacement fuel pump (15) which supplies fuel to injectors (4a) of the combustion chamber (4) through a control system 28. The system is an emergency system, fuel in normal operation being supplied by an engine driven pump not shown.

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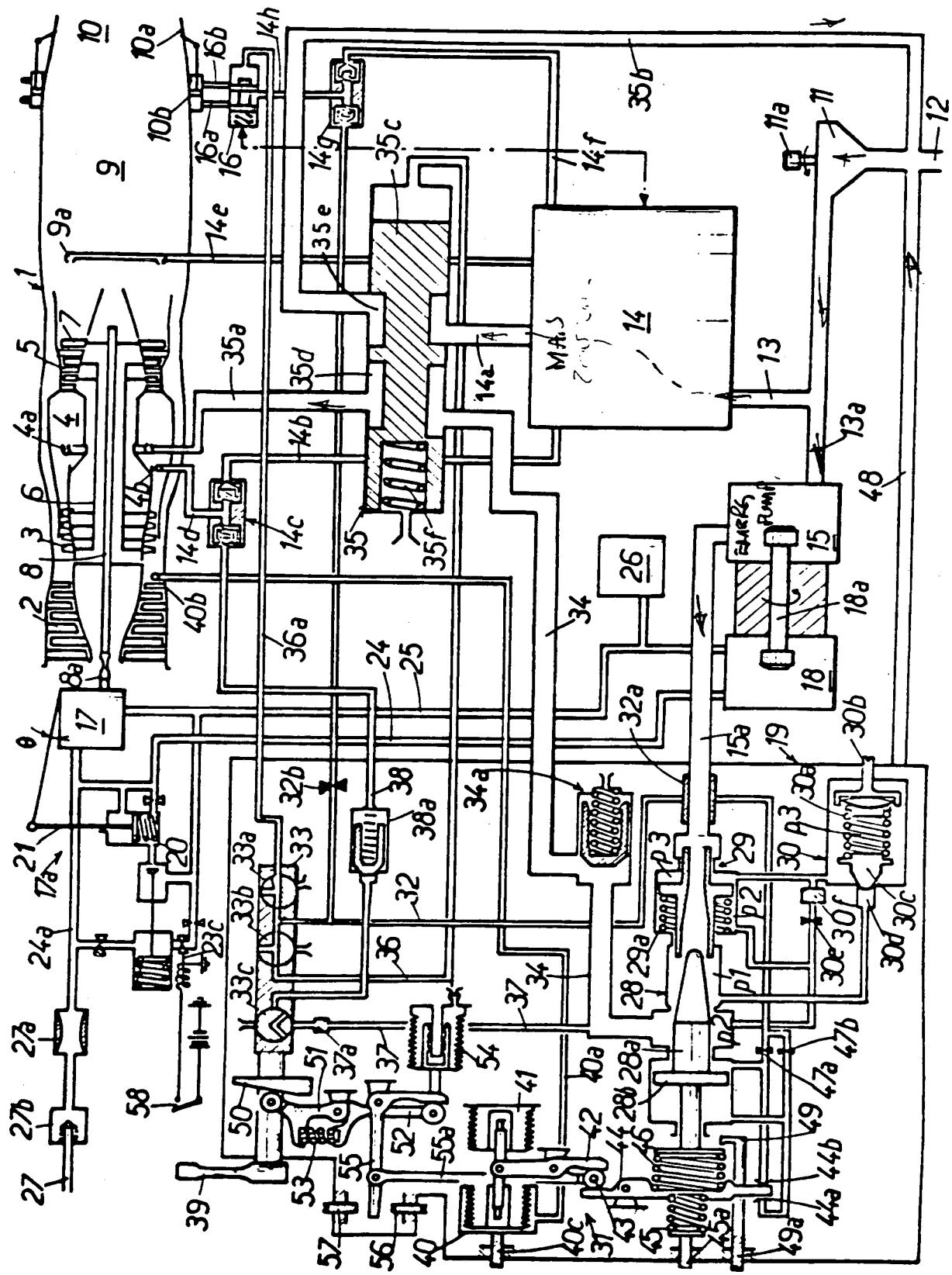


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SPECIFICATION
Aircraft Gas Turbine Engine Control

This invention relates to the control of aircraft gas turbine engines.

5 The conventional control of an aircraft jet propulsion engine comprises essentially a fuel pump driven by the engine and delivering to a flow regulator which is operated as a function of various parameters so as to provide for the fuel a passage cross-section necessary for supplying to the combustion chamber of the jet engine the appropriate fuel flow.

Assuming that the regulator is normally supplied at variable pressure, it is not possible to obtain, in general, an exact dose, except by associating with the regulator a control valve which maintains a constant value of the pressure drop across the regulator, by controlling a by-pass flow at the entry thereto. In modern jet propulsion engines, the control system must provide for both the control of the section of the jet nozzle and the control of the flow of fuel for reheat (if it is provided); some systems also provide hydraulic power for the supply of service devices of the 20 aircraft of the aircraft on which the jet engine is mounted.

Such control systems are very complex. When a jet engine comprises such a control, and above all in the case of an aircraft equipped with a single engine, it is essential to be able, if necessary, to alleviate the effects of a possible failure of the control system. It is possible to envisage use to this end of a mechanical direct control of the flow regulator, by means of the pilot's control lever.

35 However, this direct control will not alleviate, in particular, a break in the kinematic chain driving the fuel pump. It is thus desirable to be able to provide for a complete emergency control.

According to the present invention there is 40 provided a control device for an aircraft gas turbine engine comprising a first, self-regulating, pump driven by the engine and arranged to deliver hydraulic liquid to a hydraulic volumetric motor coupled to a volumetric fuel pump, the self-regulating pump including regulating means arranged to vary the amount of the delivery so as to maintain the delivery pressure to a constant value and the fuel pump serving to supply fuel to injectors of the combustion chamber of the 45 engine through the intermediary of a flow regulator.

Further, according to the present invention there is provided a control device for an aircraft gas turbine engine comprising a self-regulating pump incorporating regulating means arranged to maintain the delivery pressure constant, means providing a connection from the self-regulating pump to a hydraulic volumetric motor coupled to drive a volumetric fuel pump and a flow regulator 50 arranged to be connected between the volumetric fuel pump and the fuel injectors of the combustion chamber of the gas turbine.

The self-regulating pump may be, for example, a pump of known type, comprising a cylinder

65 arranged to rotate parallel to its axis, with a ring of bores in which pistons move and of which the rods abut against an inclined plate, associated with a drive actuated by the delivery pressure in order to vary the inclination of the plate. This 70 pump may also be a pump of the "Hele-Shaw" type with radial cylinders of which the piston rods abut against a cylindrical eccentric surface, associated with a drive actuated by the delivery pressure in order to cause the eccentricity to vary. 75 The delivery pressure of the self-regulating pump is thus maintained constant in spite of variations in the rotational speed (which is driven by the jet engine) and of the amount of the hydraulic liquid required by the hydraulic motor. It follows that the delivery pressure of the fuel pump 80 is also maintained constant. The delivery of the volumetric fuel pump is, in fact, proportional to the amount of liquid which drives the volumetric hydraulic motor, the ratio of the amounts being 85 equal to the ratio of the cylinder capacities of these two apparatus, and since the powers of these (equal for each of them to the product of the flow and the pressure) are equal, the pressure of the fuel is proportional to the pressure of the 90 hydraulic liquid approximately to the variations of the output. As a result, the fuel flow regulator is supplied at constant pressure and can thus supply an amount of fuel dispensed with precision, without being necessary to provide a regulating 95 valve.

The invention will now be described, by way of example, with reference to the accompanying drawing, the sole Figure of which is a diagrammatic representation of a control system 100 in accordance with the invention of an aircraft gas turbine.

The diagram shows an aircraft gas turbine engine 1 mounted on an aircraft (not shown) and comprising a high-pressure compressor 3, 105 following a low-pressure compressor 2 which delivers compressed air to a combustion chamber 4, provided with a fuel injection manifold 4a and igniting injectors 4b. The fuel burned in the combustion chamber 4 in the air delivered by the compressor, forms a stream of hot gases which pass successively through a high-pressure turbine 5 coupled to the high-pressure compressor 3 by a hollow shaft 6, then through a low-pressure turbine 7 coupled to the low-pressure compressor 110 2 by a shaft 8, and from thence into a re-heat (or after-burner) duct 9 equipped with a re-heat fuel injection manifold 9a and connected to a jet nozzle 10 of which the outlet section is controlled by adjustable flaps 10a actuated by a ring of 120 hydraulic actuators 10b.

A centrifugal pump 11, termed a force pump and of which the drive shaft 11a is coupled to the engine 1 by a transmission (not shown), is supplied through piping 12 with fuel from a reservoir (not shown) and delivers the fuel to two pipes 13, 13a which are connected respectively to a main control device designated as a whole by the reference 14 and to an emergency fuel pump 15 which will be described hereinafter.

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The main control device 14 is of conventional type; it is connected to the jet engine 1 and to the airframe (not shown) of the aircraft by kinematic chains (not shown), which drives a main fuel pump (not shown), and introduce to the device 14 various control parameters. The pressurized fuel which is dispensed to the device 14 leaves through a pipe 14a which is connected to the main fuel injection manifold 4a by means which will be described hereinafter. Means are provided within the device 14 for supplying igniting fuel to a pipe 14b terminating at a valve housing 14c, in turn connected by a pipe 14d to the igniting injectors 4b. These means further serve to supply, at will, re-heat fuel to a pipe 14e terminating at the re-heat injection manifold 9a, and fuel under pressure to a pipe 14f terminating at a valve housing 14g connected by a pipe 14h to a distributor 16 connected by pipes 16a, 16b to the nozzle actuators 10b. Means (not shown) are similarly provided in the main control device to operate the distributor 16 so as to adapt the outlet section of the nozzle 10, at any given time, to the flight conditions of the aircraft.

25 The emergency control device comprises essentially a hydraulic pump 17 coupled to the shaft 8 of the jet engine and driving a hydraulic motor 18 coupled to the emergency fuel pump 15, which supplies the fuel, derived from the piping 13a to a pipe 15a terminating within an emergency control casing 19, which contains all the necessary apparatus to ensure simplified control of the engine 1 in the case of malfunction of the main control device; such apparatus will be further described hereinafter.

The hydraulic pump 17 is of the rotating barrel and inclined plate type, and is coupled to the shaft 8 through the intermediary of a torque-limiting coupling 8a constituted by a rod calibrated to rupture when a predetermined torque is exceeded.

The pump 17 is self-regulating, (for example of the "Hele-Shaw" type) being associated with a regulator designated as an assembly by the reference numeral 17a, which causes variation in flow by regulating the inclination θ of the plate (not shown) against which the piston rods (not shown) of the pump abut, so as to maintain the supply pressure at a constant value.

50 The regulating member 17a is indicated diagrammatically by a piston/cylinder arrangement 20 of which the piston rod 21 regulates the inclination θ of the plate. A solenoid valve 23c operated by a switch 58 determines the value of supply pressure to the pump 17. When the valve 23c is non-energized or open, the delivery pressure of the pump 17 is maintained at 210 bars. When the valve 23c is energized or closed, the delivery pressure of the pump 17 is held at a lower value, 110 bars, for example.

The delivery pipe 24 of the pump 17 is connected to the inlet of the hydraulic motor 18, and the suction pipe 25 is connected to a hydraulic liquid reservoir 26, and is also

65 connected the output of the hydraulic motor 18. The hydraulic motor 18 is a volumetric motor, for example with pistons, with a fixed capacity and drives through a rigid coupling 18a the emergency fuel pump 15, which is also volumetric, with vanes or with gear-wheels, for example, so that the pressure of the fuel delivered into the pipe 15a by the pump 15 is proportional to the pressure of the hydraulic liquid in the pipe 24, as has been explained hereinbefore. A branch 70 24a of the delivery pipe is connected, through the intermediary of a flow-limiting valve 27a and of a restricting valve 27b, to the entry 27 of the supply circuit of the service apparatus of the airframe of the aircraft (not shown).

75 80 The emergency control apparatus contained within the box 19 comprises a flow regulator 28 receiving fuel from the pipe 15a through the intermediary of a throttle valve 29 associated with a density corrector 30, the flow regulator comprising a regulating needle 28a rigid with a piston 28b subjected on both faces to pressures which are varied by actuating means designated as an assembly by the reference 31.

85 As has been explained hereinbefore, the emergency fuel pump 15 supplies fuel at constant pressure to the pipe 15a, so that it will be able to apply corrections by means of a regulating valve to the flow dispensed through the dispensing needle 28a. In the embodiment illustrated, it has nevertheless been preferred to ensure regulation of the range of pressure of the fuel at the passage through the flow dispenser 28, by means of a regulating valve constituted by the throttle 29 associated with the density corrector 30,

90 95 particularly in order to take into account possible variations in pressure due to ageing of the hydraulic pump 17. This device 29 acts by controlling, by means of a small, constant, pressure differential, a throttle mounted in series 100 with the flow regulator upstream thereof. As can be seen in the drawing, the throttle valve 29 is biased in the opening direction by the pressure p_2 of the fuel at the outlet of the dispenser 28, assisted by a spring 29a, and in the closure direction by the pressure p_3 of the fuel discharged from the density corrector 30. This pressure p_3 is defined by the force of a spring 30a, (controllable by means of a screw 30b) which acts on a valve member 30c in the closure direction of a nozzle 110 105 115 30d, supplied at the pressure p_1 at the inlet of the regulator 28, in order to control a bleed to the outlet of this regulator through the throttle 30e protected by a filter 30f. The valve member 30c being subjected in the opening sense to the pressure p_1 , the pressure difference $p_1 - p_3$ is determined by the force of the spring 30a; the latter holds it at a constant value (which may be modified in accordance with the density of the fuel, by means of the regulator screw 30b). The 120 125 difference between the pressures p_3 and p_2 is maintained constant by the force of spring 29a. It follows that the pressure difference $p_1 - p_2$ is thus maintained constant.

A pipe 32 bleeds fuel from the pipe 15a through a filter 32a and supplies filtered fuel, on the one hand to two cocks 33a, 33b, of an assembly of three-way cocks 33 under the control 5 of the aircraft pilot and, on the other hand, through a throttle 32b, and the valve housing 14g to the distributor 16 of the nozzle actuators 10b. The outlet of the cock 33a is connected through a pipe 36a to the nozzle distributor 16. The fuel 10 dispensed by the needle 28a is lead by a pipe 34, through the intermediary of a relief valve 34a, to a shuttle valve 35, at which the outlet pipe 14a of the main regulation device also terminates and which is connected to the injection manifold 4a 15 through a pipe 35a and to the suction of the force pump 11 through a pipe 35b. The shuttle 35c of this valve 35 has two annular chambers 35d, 35e and is biased to the right in the drawing by a spring 35f; the right-hand end of the valve is 20 connected by a pipe 36 to the outlet of the cock 33b, and when this pipe is under pressure (position shown), the shuttle 35c is moved to the left, in which position the annular chamber 35d provides communication between the pipes 34 25 and 35a and the annular chamber 35e provides communication from the pipe 14a to the return pipe 35b. When the pipe 36 is not under pressure, the spring 35f moves the shuttle 35c to the right hand position in which the annular chamber 35d 30 provides communication between the pipes 14a and 35a and the shuttle 35c cuts off the pipe 34. A pipe 37 bleeds fuel from the pipe 34 and supplies through a filter 37a a third cock 33c of which the outlet is connected through a pipe 38 35 and, through a non-return valve 38a to a valve housing 14c for supply of the ignition injectors 4b.

As will be apparent from the drawing, each of the valve housings 14c and 14g, which are 40 connected respectively to a normal control pipe and to an emergency control pipe, contains a pair of stop valves each loaded by a spring and serving automatically to isolate the operative circuit from the circuit inoperative at any given time. 45 The actuating apparatus 31 is of a type capable of actuating the dispensing needle 28a, in such a manner that the amount of fuel C supplied to the injection manifold 4a through the duct 34, is regulated as a function of α and of 50 ps_3 , α being the angle of the lever and ps_3 the outlet pressure of the low-pressure compressor 2. The pilot's emergency lever 39 is distinct from the pilot's main control lever (not shown), and a blocking device (not shown) enables the pilot to 55 block that one of these two levers which is not in use. The parameter ps_3 is introduced into the emergency control system through a pair of capsules 40, 41. The capsule 40 is supplied with air at pressure Ps_3 through a pipe 40a 60 connected to a pick-up 40b disposed at the output of the low pressure compressor 2, and the capsule 41 is subjected to vacuum. A control screw 40c enables adjustment of the forces exerted by the pair of capsules. 65 The pair of capsules 40, 41 actuate a lever 42,

which transmits through the intermediary of a roller 43 the force of the capsules to a lever 44 serving to calculate the ratio C/Ps_3 and to which there is applied, furthermore, the force of a spring 70 45, adjustable by a screw 45a, the force of a spring 46 which senses the position of the dispensing needle 28a and the hydraulic return force exerted on the end of the lever 44 because it co-operates with two nozzles 44a, 44b, in order 75 to adjust the pressures applied to the piston 28b of the dispensing needle. This arrangement is known by the term "balance of forces"; for a given position of the roller 43, when the force of the capsules is not in equilibrium with the force of 80 the spring 46, the lever 44 pivots and causes variation in the effective sections of the two nozzles 44a, 44b, supplied through throttles 47a, 47b with filtered fuel, bled at 32, and discharging into the casing 19 which is connected by a drain 85 48 to the intake of the force pump 11. The variation in the effective sections of the two nozzles 44a and 44b serves to modify the pressures acting on the two faces of the piston 28b, so that the dispensing needle 28a is 90 displaced to a new equilibrium position. An abutment 49, adjusted by a screw 49a determines the minimum value of the amount of fuel C. The parameter α is introduced into the control 95 system by the hand lever 39. The latter serves to displace a linear cam 50, which itself serves to displace the roller 43 through the intermediary of a pivotal, two-part, lever 51, 52 biased apart by a spring 53, of a damping device 54 and of a lever 100 55 transmitting through a rod 55a, the displacement of the damping device of the roller 43. This roller 43 enables the application of the desired value of the ratio C/Ps_3 determined by the angle of the hand lever α . The damping device 54 is constituted by a bellows which is compressed 105 at low speeds and which distends in order to drive the lever 55 and the roller 43 to the "full gas" position, whilst filling up through openings (not shown) of small size. The spring 53 enables limits 110 to be applied to the force transmitted to the damping device 54 when the hand lever 39 is displaced from "full gas" to "idling". When the lever is displaced in the opposite sense, a break occurs in the contact between the lever 51—52, the cam and the damping device since the latter is not of sufficient length. Pivoting of the lever 55 is limited by two adjustable abutments 56, 57, which respectively define the minimum and maximum values of the ratio C/Ps_3 . 115 The assembly of three-way cock 33 is controlled by the hand lever, and the pilot has under his control the switch 58 which effects the opening and closure of the solenoid valve 23c. 120 The engine 1 is normally controlled by the main control device. The solenoid valve 23c is closed, so that the hydraulic pump 17 delivers at a reduced pressure of 110 bars, the hydraulic motor 18 drives the pump 15 at a reduced speed and the latter delivers fuel to the pipe 15a at a 125 130

pressure just sufficient to compensate for losses in the emergency control when inoperative; the valve 27b is closed and the service devices of the airframe of the aircraft (not shown) are supplied with hydraulic liquid by the main control system. The pressure being lower in the pipe 32 than in the pipe 14f, the valves of the valve housing 14g take up a position such that the pipe 14h is supplied from the pipe 14f, and the distributor 16 is actuated by means (not shown) which are provided in the main control system. The cocks 33b, 33c, are in positions such that their outlet ducts communicate with the interior of the casing 19 and thus are at suction pressure of the force pump 11, the outlet of the cocks 33a is blocked and cannot affect the operation of the distributor 16. The shuttle 35 is moved by the spring 35f into its right hand position, in which the pipe 35a (which supplies the injection manifold 4a) is connected to the pipe 14a of the main control system, and the valve housing 14c isolates the pipe 38 and provides communication between the pipe 14d (which is connected to the ignition injectors 4b) with the pipe 14b.

In case of malfunction of the main control system, the pilot operates the switch 58 in order to open the solenoid valve 23c, thus placing the plate of the hydraulic pump 17 at an inclination such that the pump supplies hydraulic liquid at a constant pressure of 210 bars; the hydraulic motor 18 then drives the pump 15 at a speed such that the pressure of the emergency fuel in the pipes 15c, 32, 34 and 37 increases to its operational value; the position of the valves of the valve housing 14g changeover, such that the pipe 14h is supplied by the pipe 32. Moreover, the pressure in the branch 24a opens the stop valve 27b, such that the service apparatus of the airframe of the aircraft will be supplied with hydraulic liquid by the pump 17.

The pilot actuates simultaneously the unillustrated device for blocking the main hand lever and unblocking the hand lever 39, and places this either in position for re-ignition (if the jet engine is flamed out) or directly in the flight position. In the re-ignition position, the cock 33a provides communication from the pipe 36a to the interior of the casing 19, so that the distributor 16 (which is not actuated by the main control system, the latter being inoperative) is returned by its spring to the right in the drawing, and so that the pressure in the pipe 14h passes into the pipe 16b and maintains the flaps of the nozzle 10a in the open position. The cock 33b is in a position such that the pressurized fuel passes from the pipe 32 to the pipe 36 and returns the shuttle 35c to the left, that is to say into the position shown in which the annular chamber 35d provides communication between the pipes 34 and 35a, thus supplying the main injection manifold 4a with fuel dispensed by the emergency control. The cock 33c provides communication between the pipes 37 and 38, so that the pressurized fuel in the pipe 37 passes into the pipe 38, returns the corresponding valve of the valve housing 14c, and

passes into the ignition injectors 4b. It is then possible to actuate an ignition device (not shown) in order to ignite the fuel atomized by the injectors 4b, which ignites in turn fuel atomized by the main injection manifold 4a. It is then possible to displace the hand lever 39 into the flight position. In this flight position, the three cocks 33a, 33b, 33c are in the position shown. The fluid under pressure passes from the pipe 32 into the pipe 36a and returns the distributor 16 to the position shown, so that the pressure in the pipe 14h passes into the pipe 16a and maintains the nozzle in the closed position. The pipe 38 is cut off so that the ignition injectors 4b are no longer supplied. The shuttle 35c remains in the position shown, so that combustion is maintained in the chamber 4 by fuel dispensed through the needle 28a, the pilot having the facility of applying by means of the hand lever 39 various values of the ratio C/Ps3 in order to control the rating of the jet engine.

If the pilot increases the selected value of the ratio C/Ps3 which is translated by a displacement of the roller 43 upwardly in the drawing and thus by a reduction in the force exerted by the capsules 40—41 on the lever 44, the latter will turn in the clockwise sense. An increase in the effective bleed section of the nozzle 44b follows and a reduction of that of the nozzle 44a, and as a result a lack of balance arises between the pressures acting on the faces of the piston 28b, this lack of balance causing displacement of the dispensing needle 28a to the left, until the resultant increase of the force applied by the spring 46 on the lever 44 returns this to the intermediate position. The amount of fuel dispensed by the needle 28a will thus increase, which will tend to reduce the pressure of fuel in the pipe 15a. Since this pressure is, as has been explained hereinbefore, necessarily proportional to the hydraulic liquid pressure in the pipe 24, the hydraulic motor 18 has a tendency to accelerate so that the pump 15 will re-establish the proportionality of these two pressures. The acceleration of the hydraulic motor 18, causing an increase in the amount of hydraulic liquid, will trigger the intervention of the control 17a, which will maintain at 210 bars the hydraulic liquid pressure in the pipe 24, so that the fuel pressure in the pipe 15a, will be returned to its original value.

The emergency control device which has just been described enables the following advantages to be achieved:

- 120 1. The volumetric pump 15 is driven at a variable speed, and the necessity is thereby avoided of returning a part of the fuel to the suction intake, which gives rise to an undesirable heating up of the fuel and more rapid wear of the pump. The pump supplies the exact amount of fuel which the engine consumes, and no more.
- 125 2. The hydraulic motor 18 is a motor with fixed capacity and is driven by the hydraulic liquid delivered by the self-regulating pump 17. It is thus possible to make use of a hydraulic liquid

which is much more viscous than the fuel and does not give rise to the harmful chemical reactions of hot fuels on parts of copper or of silver. The viability of the assembly of the pump and of the hydraulic motor is thus high.

- 5 3. Loss of hydraulic liquid in the region of the pump 17, situated in the nose of the jet engine and driven by the latter, does not give rise to dangerous characteristics as would arise if the
10 pump operated with fuel.

4. The fuel pump 15 is not, as in conventional constructions, driven by a mechanical kinematic chain and cannot therefore be immobilised by malfunction of such a kinematic chain.

- 15 5. It is possible to modify the pressurization of the fuel by the pump 15. It is possible to set the hydraulic pump 17 at rest or idling, by operating on a simple electric switch and to stop the fuel pump 15 or to allow it to idle, which will reduce

- 20 the wear. Wear on the hydraulic pump 17 is also saved by the reduced pressure of its delivery.

6. The hydraulic fluid which provides drive to the emergency fuel pump thus ensures provision of hydraulic liquid to service devices of the
25 airframe of the aircraft; the latter enables the omission of a kinematic chain without the consequential multiplication of the number of pipes.

- 30 Persons skilled in the art, will readily understand that it is possible to modify the described arrangement so as to use a device in accordance with the invention as a main control.

Claims

1. A control device for an aircraft gas turbine
35 engine comprising a first, self-regulating, pump driven by the engine and arranged to deliver hydraulic liquid to a hydraulic volumetric motor coupled to a volumetric fuel pump, the self-regulating pump including regulating means arranged to vary the amount of the delivery so as
40 to maintain the delivery pressure to a constant value and the fuel pump serving to supply fuel to injectors of the combustion chamber of the engine through the intermediary of a flow regulator.

45 2. A device according to claim 1, wherein the volumetric hydraulic motor and the volumetric fuel pump have a fixed capacity, such that the pressure of the fuel delivered by this pump is constant and so that the flow regulator does not include a regulating valve.

50 3. A device according to claim 1 or claim 2, wherein the delivery pipe of the hydraulic volumetric pump is provided with a branch arranged to be connected to the supply circuit of

55 service devices of the airframe of the aircraft on which the engine is mounted.

4. A device according to one of claims 1 to 2, wherein the device constitutes an emergency control system in which the volumetric pump

60 coupled to the hydraulic motor is separate from the pump supplying the main control, a shuttle valve providing for changeover of the supply circuit of injectors either from fuel supplied by the main control, or fuel supplied by the emergency fuel pump, the pipe which leads the main fuel being then connected to a return pipe.

5. A device according to claim 4, wherein the injector supply circuit starting from the emergency fuel pump is provided with means for

70 the supply of fuel under pressure, an actuating device for controlling the ejection section of the jet nozzle of the engine so as to maintain as required the ejection section either at a maximum value, or a minimum value.

75 6. A control device for an aircraft gas turbine engine comprising a self-regulating pump incorporating regulating means arranged to maintain the delivery pressure constant, means providing a connection from the self-regulating
80 pump to a hydraulic volumetric motor coupled to drive a volumetric fuel pump and a flow regulator arranged to be connected between the volumetric fuel pump and the fuel injectors of the combustion chamber of the gas turbine.

85 7. A control device for an aircraft gas turbine engine substantially as hereinbefore described with reference to the accompanying drawing.

8. An aircraft gas turbine engine incorporating a control device according to any one of claims 1
90 to 7.

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